

## THE JAHNSIAN STEPS TO GEOLOGIC SAFETY: THE ENGINEERING GEOLOGIC APPROACH

William F. Cole  
Ted M. Sayre  
William R. Cotton

William Cotton and Associates  
330 Village Lane  
Los Gatos, California 95030

### Introduction

*"No man-made structure that is coupled with the ground can be regarded as entirely free from physical hazard and risk."* This statement by the late Dick Jahns, renowned engineering geologist and distinguished professor at Caltech, Penn State and Stanford, is especially true of hillside terrain in seismically active regions. Since the end of World War II, such hillside terrain has been the focus of expanding development throughout the coastal ranges of California. These developments have offered a challenge to geologists and engineers who strive to make structures "hazard free", or at least reduce the risk associated with a hazard to a tolerable level. Standard procedures, analytical techniques and data bases have been developed over the years to enable the modern geologist and engineer to perform sophisticated hazard evaluations. Unfortunately, many developments continue to be plagued by geologic and geotechnical problems that could have, and should have, been recognized and mitigated prior to final project acceptance.

A lack of thorough and accurate engineering geologic and geotechnical engineering input during the initial investigative stages of these developments is frequently a significant factor in their failures. Ground failures sometimes result in billions of dollars of property damage and severe emotional distress that accompanies the loss of a home, devalued property or, in extreme cases, loss of life. Case studies of such ground failures, performed either for research, peer review or forensic purposes, frequently involve examination of previous geologic investigations that have not accurately predicted the ground failure or consequences of the failure. The consultants who have conducted these "postmortem" studies appear to have developed a higher degree of respect for the complexity of geologic and geotechnical conditions contributing to ground failures than consultants without this experience.

As reviewers of development applications for 12 communities in the San Francisco Bay area, we are continually confronted by the shortsightedness and incompleteness of many engineering geologic reports that present very little understanding of geologic hazards. The most common deficiencies we come across in the reports we review are the result of *incompetence* or *irresponsibility* on the part of the investigator(s).

Part of the *incompetence* problem is that the field investigative tasks are sometimes poorly planned and delegated to staff without adequate training in the completion of thorough engineering geologic investigations. Included with this group are some geotechnical engineers who do not understand geologic processes, and therefore do not perceive the need for, engineering geologic input. This improper approach is sometimes compounded when engineering-oriented firms use geologists who also are not qualified to conduct thorough engineering geologic studies. Typically, such an approach results in failure to fully recognize or understand hazards, or an inability to make the transition from hazard recognition to meaningful assessment of the risk associated with the hazard.

A smaller group of consultants perform their work in an *irresponsible* manner. Included with this group are investigators who are aware of a hazard, but try to downplay its significance without fully investigating the potential problem. In some cases, consultants deliberately perform a low-cost, limited scope of work, knowing that the reviewers will require additional studies at greater cost to their clients. We have seen some consultants choose to perform a limited geotechnical engineering study, knowing that the work would be insufficient, not up to the standard of care, and likely to be rejected by the city's reviewers as being inadequate. Later, using the reviewers' rejection as a lever, the consultant can then persuade his or her client to fund a full engineering geologic investigation. This normally has to be followed up with



a second geotechnical engineering study to address issues discovered during the geologic investigation!

Unfortunately, episodes like the one above are not as rare as we would like to believe. In many aspects, it seems as if the standards of investigative practice are less today than they were in the late 1960s and 1970s, after great strides had been achieved in recognition and characterization of hillside hazards. Jahns (1974) made the following statement in reference to reports submitted to Los Angeles County for review during the early days of geologic review: *"Nearly half of the reports had been submitted by people with little or no experience in geology as applied to engineering works, and at least half of them either were essentially without pertinent data or presented no more than generalized information rather crudely abstracted from the published record. Little more than one out of ten contained maps or sections that had been prepared at an appropriate scale or in suitable detail."* It is somewhat dismaying that this pattern of incomplete and poorly supported work continues to plague the profession.

Judging from the poor quality of many of the geologic and geotechnical reports we review annually, it is apparent that some geologic consultants are not aware that there is a well-defined method of conducting geotechnical investigations, and related hazard analyses, that can significantly improve investigative results. Dick Jahns spoke of this issue frequently to geology students at Stanford University during his tenure from the mid-1960s to the early 1980s. This forum provides a good opportunity to refresh all engineering geologists of the four "essential" steps of a engineering geologic investigation, as Jahns outlined over two decades ago.

#### The Jahnsian Investigative Steps

The engineering geologic approach contains the following four basic steps:

1. *Recognition* of local geologic conditions and recognition of any geologic hazards;
2. *Characterization* of the local conditions and hazards;
3. *Assessment* of the risk posed by the hazards; and
4. *Mitigation* of the hazard so that the subject property can be safely used.

To our thinking, these four steps are both logical and necessary. Furthermore, these steps must be performed in proper sequence: one cannot fully assess the risk posed by a hazard until the characteristics of that hazard are fully

understood. Similarly, a hazard cannot be accurately characterized unless the presence of the hazard has been recognized.

The most common hazards and constraints in the coastal regions of California are various forms of slope instability, susceptibility to strong seismic ground shaking, surface fault rupture, flooding, and expansive soil and bedrock materials. For simplicity, our discussion of the basic steps to the engineering geologic approach will emphasize the problems with development in landslide terrain. It is apparent, however, that the approach should be applied to all types of geologic hazards and conditions.

#### Step 1 - Recognition

It is obvious that the investigator must possess sufficient qualifications to enable hazards to be recognized. If a hazard is not recognized, then subsequent steps cannot be satisfactorily completed no matter how qualified the geologist or engineer participating in these phases. The record of case histories clearly demonstrates that many failures can be traced to deficiencies in this vital first step.

Recognition of a landslide hazard can be enhanced by performing the appropriate investigative tasks in proper sequence. First, the best available maps, historical aerial photographs and other documents should be reviewed to see what topographic features are present and to determine whether any significant geologic features have been previously mapped. Several communities possess their own set of geologic maps and, in some cases, geologic hazard maps. These documents provide a wealth of data which can help an investigator almost instantaneously become familiar with local geologic conditions. Frequently, we have found that these maps provide more accurate information than the site-specific maps prepared by the consultant as part of his investigation.

Site-specific surface mapping of geologic exposures and geomorphic features provide the second task in the hazard recognition phase. Many times, this critical task requires relatively little time to complete, and it is often the only dependable way to identify a number of potential hazards. For recognition of existing landslides, the surface boundaries and probable subsurface configurations must be determined, or at least approximated, from field observations. Figure 1 portrays the increasing level of detail and understanding that accompany a geologist's progression from topographic map and aerial photographic interpretation to site-specific mapping.

Performing both of these two tasks is critical to the geologic safety of a project. Without adequate identification of site conditions and associated hazards, the remaining three steps cannot be conducted with success.



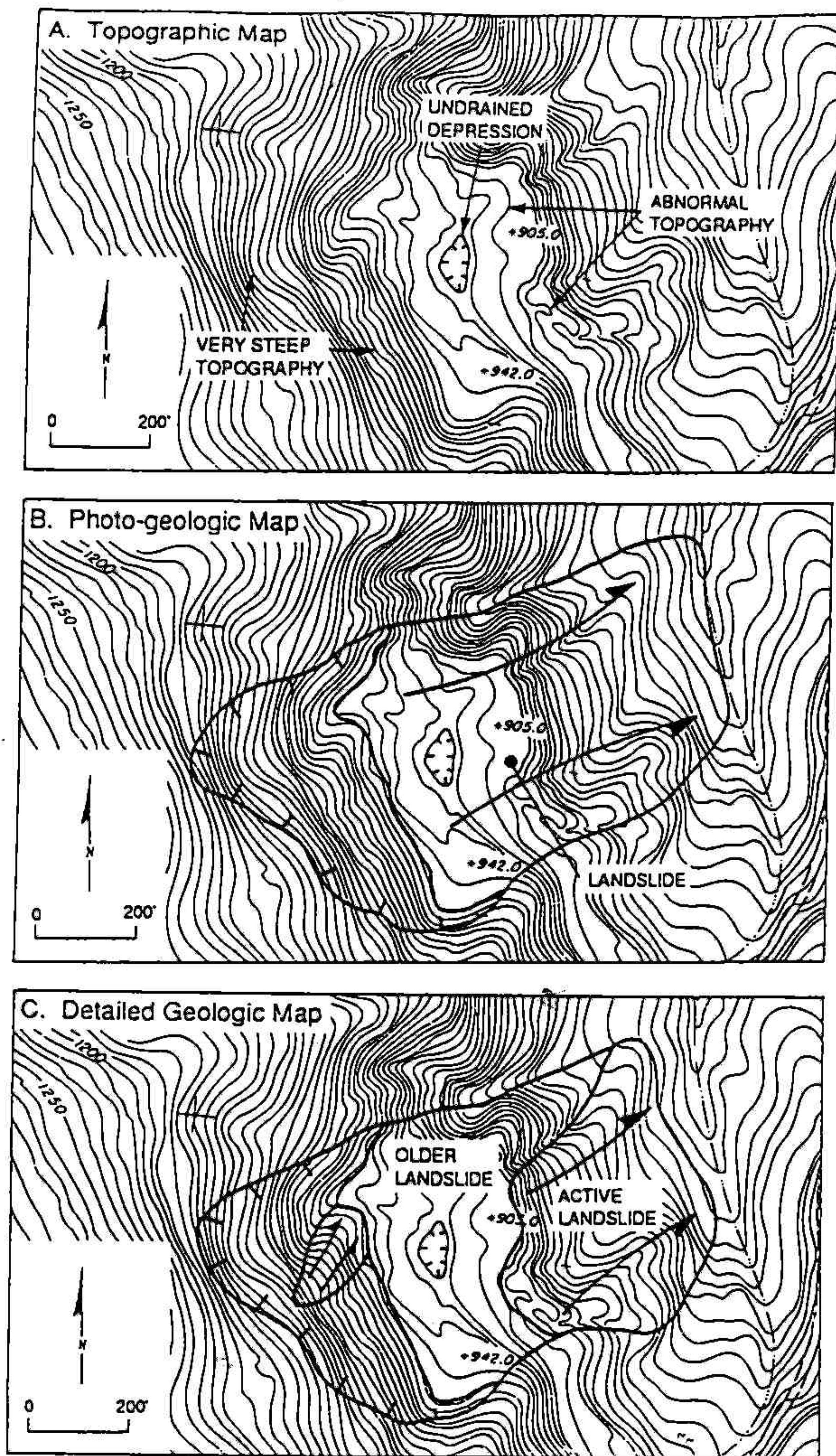


Figure 1. An example of three steps in landslide recognition, based on the use of topographic maps (A), aerial photographs (B), and geologic mapping (C).



If a hazard has not been recognized, it cannot be characterized for subsequent analysis and assessment.

## Step 2 - Characterization

Once a hazard has been recognized, it requires more detailed study in order to obtain sufficient physical data as a basis for further analysis and assessment. Each type of hazard has associated parameters that must be determined before its future behavior can be judged and an acceptable assessment about risk can be made. For landslide evaluations, these parameters typically include: the physical dimensions (length, width and depth) of the landslide; topographic conditions; engineering properties of landslide materials, rupture surfaces and underlying earth materials; ground water conditions; probable modes of failure; and seismic shaking considerations. Obviously, detailed surface mapping and subsurface exploration must be carried out in order to determine these parameters.

A critical first step in this phase is the production of a detailed engineering geologic map and cross sections of the property. In hillside terrain, there is absolutely no substitute for detailed field mapping and profiling performed by an experienced engineering geologist. Unfortunately, this step is the most common missing element in an engineering geologic investigation for residential properties in hillside terrain. We often see that the mapping phase is performed hurriedly in an effort to proceed with subsurface exploration. As a result, borings and excavations are not sited in strategic locations, the significance of key materials are not recognized, and samples taken for laboratory testing do not reflect the most hazardous condition.

Prior to subsurface exploration, one or more preliminary geologic cross sections should be prepared showing the slope profile, limits of landsliding based on surface mapping, and anticipated depth(s) of subsurface rupture surfaces. Using the geologic map and preliminary cross sections, subsurface excavations can be sited at those locations that have the highest probability of achieving the needed data.

Three major objectives of the subsurface exploration program should be: complete characterization of the material units present, determination of landslide geometry, and collection of representative samples of each critical material unit for laboratory testing. We have found that a disturbing number of consultants do not follow a standard logging procedure, despite the relatively high cost and physical disruption that this phase of work can entail in comparison to other investigative tasks. Rather than attempting to maximize the amount of information from each subsurface excavation, and perhaps limiting the number of excavations, many consultants

attempt to complete as many excavations as possible in a short time frame, as if the quantity of borings or test pits are a substitute for quality.

It has become clear that excavations which enable the geologist and engineer to directly observe and sample subsurface materials and contacts, such as exploratory trenches and large-diameter boreholes and shafts, are potentially much more valuable than small-diameter borings that are sampled at rigid intervals without prior knowledge of the materials or conditions existing at depth (Hutchinson, 1983). Despite abundant evidence to the contrary, some of our colleagues still do not realize that landslides can consist of a sequence of stiff, or even rock-hard, material that has failed along one or more very thin and very weak surfaces. As a result, the weakest materials frequently are not sampled, and resulting stability analyses based on the high strengths determined from laboratory testing of essentially intact material yield erroneously high, and thus dangerously misleading, factors of safety.

Prior to initiation of a particularly extensive subsurface program, it is often beneficial to solicit comments from the reviewer. In this way, the consultant has the opportunity to incorporate any suggestions made by the reviewer into his work plan, and the reviewer has the opportunity to inspect the subsurface exploration program while in progress. Communication with the reviewer can often go a long way toward completing a successful characterization of hazards affecting a particular site.

## Step 3 - Risk Assessment

If the hazard characterization step is adequately carried out, the consultant is now in a position to assess the level of risk that the hazard might impose on the intended land use. However, proper assessment of the risk posed by a particular hazard can not be completed until adequate hazard evaluation and analysis have been performed. For most sites, it is not possible to forecast the exact timing of a geologic event. However, it is often possible to closely estimate the probable factors contributing to active geologic processes and the effects of those active processes on a particular site. In order to complete an accurate risk assessment, the engineering geologist must be aware of the conditions and sequence of events that led to formation of the hazard. Thus, for existing landslides, the engineering geologist must be cognizant of the influences of external factors such as rainfall, drainage grading and earthquake shaking, as well as possess a good idea of the mechanisms and characteristics of previous episodes of sliding. This information must then be transmitted to the geotechnical engineer so that appropriate parameters and analytical methods are used to analyze the stability of the landslide.



Even though some relatively sophisticated analytical methods have been developed to analyze slope stability, these methods can be easily misused, due to lack of data or invalid assumptions, to yield high factors of safety or low displacement computations. Consequently, the geologist must help to define the parameters used in analyses performed by the geotechnical engineer, because the geologist better comprehends the time and processes involved with hillslope evolution and landslide sensitivity to external factors. Key parameters that should be determined by the engineering geologist include landslide geometries, ground water levels, and earthquake shaking values. In addition, the engineering geologist can play a vital role in the selection of proper shear strength values, either by directly sampling the weakest materials, or by identifying which materials should be sampled for laboratory testing.

To summarize this step, following recognition and characterization of an existing landslide or other slope, a stability evaluation should be performed that incorporates the engineering geologist's understanding of: landslide type; geologic processes that may impact the stability of the slope; configuration of existing and potential rupture surfaces, orientation of bedding planes and other structural features; and any other clues from the earlier investigative phases that could aid in the prediction of future slope behavior. In addition, impacts from future development

plans (e.g., response of natural ground water levels to residential irrigation and septic leachfields) should be included in the geologic evaluation.

#### Step 4 - Mitigation

After the likely long-term behavior of the landslide or slope in question has been evaluated, and the associated risks to proposed development have been assessed, formulation of mitigation measures can begin. Mitigative solutions for landslide hazards include setbacks from potentially unstable ground, alterations of existing surface drainages, construction of subsurface drainage improvements, removal combined with or without reconstruction of unstable material, and various forms of retaining structures to buttress unstable slopes. The effectiveness of these and other mitigation measures are highly dependent on adequate completion of the three preceding steps. If an accurate assessment of future movement has not been performed, then the proposed method of correcting, avoiding or living with that assessment may be insufficient to prevent the adverse consequences of failure. If the mitigation measures do not adequately remedy adverse geologic conditions, then the hazard will eventually result in damage. Thus, through incomplete mitigation, the geologist and engineer can mislead their client, and the community, into a false belief that occupants of a particular property are protected from

INVESTIGATIVE STEPS	INVESTIGATIVE TASKS	PROFESSIONAL RESPONSIBILITY (Primary/Secondary)
1. Recognition	<ul style="list-style-type: none"> <li>• Review of available maps and analysis of aerial photographs</li> <li>• Field reconnaissance and geologic mapping</li> <li>• Identification of geologic hazards</li> </ul>	<p>Engineering Geologist ..</p> <p>↓</p>
2. Characterization	<ul style="list-style-type: none"> <li>• Detailed geologic mapping and profiling</li> <li>• Preparation of preliminary geologic cross sections</li> <li>• Selection of strategic locations and depth requirements for subsurface exploration</li> <li>• Geologic logging of exploratory excavations</li> <li>• Collection of subsurface samples for testing</li> <li>• Assignment of geotechnical testing program</li> </ul>	<p>Engineering Geologist</p> <p>↓</p> <p>Engineering Geologist/Geotechnical Engineer Geotechnical Engineer</p>
3. Risk Assessment	<ul style="list-style-type: none"> <li>• Synthesis of office, field and laboratory test data</li> <li>• Hazards evaluation (low-moderate-high)</li> <li>• Numerical analysis of potential hazards</li> <li>• Determination of risk associated with specific land-use</li> </ul>	<p>Engineering Geologist/Geotechnical Engineer Engineering Geologist Geotechnical Engineer/Engineering Geologist Engineering Geologist/Geotechnical Engineer</p>
4. Mitigation	<ul style="list-style-type: none"> <li>• Decisions of tolerable risk and consideration of client needs, local ordinances and codes</li> <li>• Development and evaluation of mitigation alternatives</li> <li>• Disclosure of limitations associated with design options</li> </ul>	<p>Engineering Geologist/Geotechnical Engineer</p> <p>Geotechnical Engineer/Engineering Geologist</p> <p>↓</p>

Table 1. Summary of the Jahnsian investigative steps.



the consequences of unsafe geologic conditions.

It is important for the geologist and engineer to realize that although design of stabilization or corrective measures is formulated on a technical basis, approval and implementation of mitigation measures also involves very important political, social and economic considerations. For example, a perfectly acceptable technical approach may not be viable if necessary cooperation between property owners is lacking, or if the local community has adopted ordinances restricting the amount of earth movement or construction that can take place. It is unproductive to design an engineered solution that will not be allowed due to restrictions in retaining wall heights, or other policies directed toward minimizing visual impacts. In addition, communities that have become sufficiently aware of their natural hazards generally have specific ordinances which govern acceptable land uses on various types of hazardous terrain. For the engineering geologist working in urban hillside areas of California, it should be a professional responsibility to become familiar with local regulations governing permissible land development uses and construction limitations.

### Conclusions

The four steps discussed above and summarized in Table 1 form the fundamental framework of an engineering geologic investigation. These steps must be performed completely, and in proper sequence, in order for appropriate measures to be designed to mitigate a particular hazard. We should all be reminded that the approach outlined herein reflects the creed of engineering geologists. Recognition of, and action consistent with, these fundamental steps by the investigator enables the investigation to be conducted more coherently and improves the reliability of technical conclusions.

Finally, geologists and engineers should not overlook the importance of proper construction methods. Even if all four of the Jahnsian steps outlined above have been completed accurately and thoroughly, the final product may fail if implementation of the mitigation measures does not follow the design of those measures. For that reason, it is crucial that the engineering geologist and geotechnical engineer stay closely involved through completion of project construction. Close examination of final plans, geotechnical field inspections (e.g., mapping of cut slope geology, excavations for piers, measurements of cut and fill slopes, testing of fills, etc.) and monitoring of grading and foundation-construction activities must be performed by qualified personnel to ensure that the actual construction follows design, and that appropriate revisions are undertaken when unanticipated conditions are encountered. As explained by Leighton (1966), an "As-Built Geologic Map" should be prepared for developments

characterized by complicated geology and numerous hazards. In addition to documenting the engineering geologist's role in project construction, this map can be used for reference during subsequent site investigations or redesign.

### References

- Hutchinson, J. N., 1983, Methods of locating slip surfaces in landslides: *Bulletin of the Association of Engineering Geologists*, v. 20, p.235-252
- Jahns, R. H., 1971, Geologic hazards, associated risk, and the decision-making process, in *Earthquake Risk: California Legislature Joint Committee on Seismic Safety, Proceedings of Earthquake Risk Conference, Sacramento, CA, p.39-53* (reprinted in *Bulletin of the Association of Engineering Geologists*, v. 20, p. 215-229).
- Jahns, R. H., 1974, Some historical perspectives on response to geologic hazards, in *Proceedings of Workshop on Physical Hazards and Land Use: A Search for Reason: San Jose State University Department of Geology, San Jose, CA, p. 105-112* (reprinted in *Bulletin of the Association of Engineering Geologists*, v. 20, p. 230-234).
- Leighton, F. B., 1966, Landslides and hillside development, in *Engineering Geology in Southern California, Special Publication of the Association of Engineering Geologists: Los Angeles, CA, p.149-204*.